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COSMIC X-RAY PHYSICS

Grant NAG 5-629 /

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SEMI-ANNUAL STATUS REPORT

to

THE NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

January 1, 1985 - June 30, 1985

Submitted by

The Space Physics Group

The University of Wisconsin-Madison

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### Introduction

This is our semi-annual progress report for NASA grant NAG 5-629 "Cosmic X-Ray Physics". The activities covered are generally the same as those covered under the old grant NGL 50-002-044.

### I. Diffuse X-ray Spectrometer (DXS)

This program and the associated instrument development are presently funded by NASA as part of SHEAL I. The instrument is scheduled for delivery to Goddard about January 1, 1985.

DXS has been flown twice as a rocket payload. The observation times were really too small for meaningful X-ray data to be obtained. But the background data we have collected have been helpful in the design of the satellite instrument.

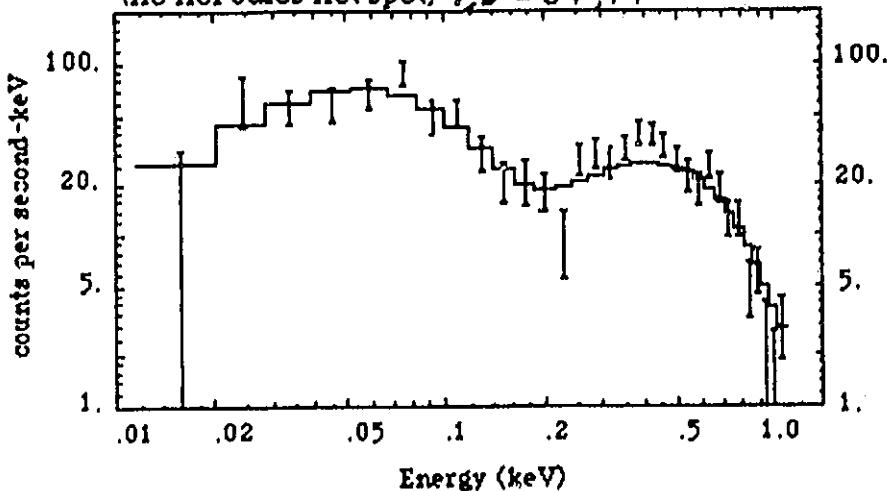
### II. Ultra-Soft X-ray Background

We continue to analyze the data collected from the UXT instrument which was flown on May 9, 1984, as well as plan and prepare for a second flight scheduled for January 10, 1986. UXT consists of three mechanically-collimated X-ray gas proportional counters with window/filter combinations which allow measurements in three energy bands, Be (80-110 eV), B (90-187 eV), and O (284-532 eV). Each proportional counter has a field of view of about 15 degrees. The Be band measurements provide an important constraint on local absorption of X-rays from the hot component of the local interstellar medium, since X-rays in this band have a mean free path of only  $10^{19} \text{ cm}^{-2}$  of neutral hydrogen column density. The O band covers energies not previously measured before.

The Fe band data show no evidence of electron or UV contamination, while the B band data show some slight contamination by UV photons or electrons. The O band detector was highly contaminated by incident UV and/or electrons. Extensive work is now being performed in preparation for the refly to understand the contamination and to make the O band detector insensitive to it.

Some analysis of the Be band data was presented at the AAS meeting, January 13-16 at Tucson, Arizona. We found that our standard two component model, which fit the all sky survey B, C and M band data, predicts too much Be band flux in all observed directions. However  $0.5 \text{ } 1 \times 10^{19} \text{ cm}^{-2}$  of local neutral hydrogen absorption is sufficient to bring the Be band flux down to observed levels without significantly affecting the predicted B, C and M band rates. No additional components are required to explain our Be band observations.

Pulse height data and model from UXT Be detector  
for a section of the UXT scan path just north of  
the Hercules hot spot;  $\ell, b = 84^\circ, 74^\circ$



Plan for UXT's reflly concentrate on studying the relationship between the soft X-ray emission and the galactic neutral gas. Specifically we have the opportunity to examine a low  $N_{\text{H}}$  region near the galactic pole, another low  $N_{\text{H}}$  region near  $\lambda, b$  of  $150^{\circ}, 50^{\circ}$ , and two directions in the galactic plane, one towards nearby  $N_{\text{H}}$  (Taurus cloud at  $\sim 100$  pc), the other towards no nearby  $N_{\text{H}}$  with  $\lambda \sim 240^{\circ}$ . An additional result of this reflly will be measurements of the plane-to-pole intensity variations in different X-ray energy bands which may shed light on certain idealized models of the galactic distribution of the hot component of the ISM.

### III. High-resolution X-ray Detector Development

We have continued work on the development of a calorimetric detector for high-resolution spectroscopy in the  $0.1 \text{ keV} - 8 \text{ keV}$  energy range. Progress is encouraging, and we hope eventually to fly a simple mechanically collimated experiment on a sounding rocket to observe the diffuse background and test a flight cryogenic system under realistic conditions. This would be followed by a fine-pointed experiment with a GSFC light-weight aluminum foil mirror to make detailed observations of supernova remnants, using either another sounding rocket or preferably a SPARTAN carrier.

We have obtained a resolution of  $80 \text{ eV FWHM}$  at  $6 \text{ keV}$  with a germanium thermistor supported on graphite fiber leads and operating at  $0.3 \text{ K}$ . This same detector was sent to GSFC and run at a base temperature of  $0.1 \text{ K}$ . Although it had to be overbiased to bring the detector temperature up near  $0.3 \text{ K}$ , the resolution improved to  $60 \text{ eV FWHM}$  (almost three times better than the best solid state detectors). An identical detector made with germanium doped for  $0.1 \text{ K}$  operation should have a resolution of  $15 \text{ eV FWHM}$  when operated at this temperature (although statistics on trapped charge are

expected to broaden this to 19 eV FWHM), and we are in the process of obtaining suitable material.

Spatial studies of silicon detectors with ion implanted thermistors have been made using a scanned X-ray beam to investigate the cause of excess broadening in these devices. It appears that the X-ray peaks are broader than the thermal noise because of spatial variations in the amount of energy lost to trapped charge. About one-third of the total energy of an X-ray absorbed in silicon goes into the production of electron-hole pairs, and at low temperatures these generally do not recombine, but are trapped at various kinds of imperfections in the crystal lattice. A free charge carrier that is trapped by such an imperfection or impurity falls to a particular energy level within the bandgap that depends on the kind of imperfection. The energy released on trapping is usually converted directly to phonons (heat) and can be detected by the thermistor. The remaining energy, determined by the trapping level, is lost to this metastable state for times very long compared to the thermal time constant of the detector. Charge produced by X-rays absorbed well below the surface of the silicon chip seems to be trapped primarily on the electrically-active impurities with which it is doped. The energy levels associated with these impurities lie very close to the band edges, and therefore little energy is recovered when charge carriers are trapped, and a large part of the third of the X-ray energy which went into producing the free carriers never shows up as heat. Charge produced by X-rays absorbed near the surface, on the other hand, appears to be trapped on lattice dislocations produced by mechanical damage introduced when the chip was fabricated. The energy levels for carriers trapped on such dislocations tend to be deep within the bandgap, and a substantial fraction of the ionization energy is recovered in the trapping process. This results in

larger thermal pulse-heights for X-rays absorbed near the surface, but the change in thermalized energy with depth of absorption smears out the X-ray peak compared to the thermal resolving power of the detector.

To overcome this difficulty, we are investigating the possibility of intentionally introducing two impurities which have energy levels for trapped electrons and holes which are near the center of the bandgap and within 40 meV of each other. When the electron and hole from an ionization are individually trapped, the sum of their binding energies will be within  $\sim .04$  eV of the energy originally expended in the ionization, and the full X-ray energy will end up as heat.

Pairs of transition metal impurities exist which provide the desired levels in silicon, and they are being investigated. It is problematical, however, whether a single pair of impurities can be introduced which sufficiently dominate the total number of imperfections to ensure that essentially all free carriers produced are trapped to the desired energy levels. As an alternate solution to the thermalization problem, we have tried to use some semimetals and narrow bandgap semiconductors as the X-ray absorber instead of silicon. In the case of semimetals, the concentration of free electrons at zero temperature is high enough to ensure rapid recombination of X-ray induced ionization, but not so high as to contribute excessively to the specific heat. Narrow bandgap semiconductors have no free carriers at  $T = 0$ , but the total energy tied up in ionization can be neglected if the gap is sufficiently small. Experiments with HgCdTe compounds have shown essentially 100% thermalization of X-ray energy, and they have sufficiently low heat capacity to be used in the construction of detectors with energy resolution of 5 eV FWHM or better. This is not as good

as could be achieved with an all-silicon detector, but would be very useful for many astrophysical spectroscopy problems.

#### IV. 21 cm Observations and Analysis

In collaboration with F. J. Lockman of the National Radio Astronomy Observatory (NRAO), we have completed tests of our ability to remove stray radiation from 21 cm observations. The remaining uncertainty in our column density measurements is about  $5 \times 10^{18} \text{ cm}^{-2}$ , an order of magnitude improvement over previous measurements. A description of our method and the results of the tests have been submitted for publication along with a detailed study of the region with the lowest known hydrogen column density. Using the NRAO 43 m telescope we found no column densities less than  $4.5 \times 10^{18} \text{ cm}^{-2}$ . It is unlikely that significant unresolved structure exists, but we are analyzing data from the NRAO 90 m telescope to confirm this. This result implies that the galactic neutral gas layer has optical depth greater than 2, everywhere, to extragalactic radiation with energy less than 100 eV.

#### V. Theoretical Work

Edgar completed a paper extending the work of Cox and Anderson (1982) on the soft X-ray background as a blast wave viewed from within. The new features include the incorporation of thermal conduction effects, evolution in a preexisting cavity, a novel approach to the explanation of the anticorrelation with hydrogen column density, a discussion of the effects of the onset of cooling at the edge, and the UXT bands.

Additional projects underway between Edgar and Cox prior to Edgar's departure to a post doc at the University of Virginia include explanation of abundance depletion effects, modelling of Loop I, and the beginning of a project to generalize the Local Bubble results to larger and older explosion systems.

Cox has been on leave of absence for the entire period, at Rice University, supported by an NSF grant there. He will return to Wisconsin in the fall. This has been a very active period for him, resulting in collaborations on the Cygnus Loop and radiative shock waves with Jeff Hester and John Raymond (see publications) and on the general behavior of SNR evolution. Additional collaborations with Don Clayton and Curt Michel have addressed the importance of the Local Bubble implied by the soft X-ray background to cosmic ray interpretation.

Cox and McCammon have reanalyzed the Einstein satellite IPC measurements of M101 to place useful limits on the number and evolution of supernova remnants in that galaxy. The most significant limits were on evaporative remnants. The possibility of a McKee and Ostriker (1977) interstellar medium were shown to be very severely constrained to both a low SN rate and low remnant densities.

There was heavy Wisconsin representation at a NRAO workshop on the galactic halo in June where the possible contributions to the X-ray background of a galactic halo were rediscussed. Cox gave an invited presentation on the Disk-Halo connection and argued that both the soft X-ray background and the cosmic ray power (inferred from the popular leaky box model) set important limits on the possible halo properties.

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# On leave of absence

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submitted to Ap. J..

"The Disk-Halo connection" and "Reflections on the Workshop," Cox, D. P.,  
invited and contributed papers to the NRAO workshop on the Galactic  
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"The Soft X-ray Background as a Supernova Blast Wave Viewed from Inside:  
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TALKS

"A Model for the Soft X-ray Background," Edgar, R. J., Rice University Space Physics Colloquium, March 1985.

"Supernova Remnants and the Interstellar Medium," Cox, D. P., Rice University Space Physics Colloquium, March 1985.

"The Disk-Halo Connection," Cox, D. P., invited presentation to the NRAO workshop on Galactic Halos, June 1985.

"The Soft X-ray Background as a Blast Wave Viewed from Inside," Edgar, R. J., contributed to the AAS meeting in Charlottesville, VA, June 1985.

"A Model of the Soft X-ray Background," Edgar, R. J., UW-Madison Astronomy Colloquium, May 1985.

"Structure in Low H I Column Density Regions," Jahoda, K., McCammon, D., and Lockman, F. J., at NRAO workshop on Galactic Halos, June 1985.

"H I Observations Without Stray Radiation," Jahoda, K., McCammon, D., and Lockman, F. J., at NRAO workshop on Galactic Halos, June 1985.

"Is There a Galactic Halo?" invited panel discussion, McCammon, D., NRAO workshop on Galactic Halos, June 1985.

"A Thermal Microcalorimeter for High-Resolution Spectroscopy," McCammon, D., Guelph University, Physics Dept. Colloquium 1985.

"Limits on a Galactic Halo from 0.5-1 keV Diffuse X-ray Emission," Sanders, W. T., Greenbank (W.Va.) Workshop on "Gaseous Haloes of Galaxies," May 1985.

"Experimental Tests of a Single-Photon Calorimeter for X-ray Spectroscopy," McCammon, D., Fermilab Colloquium, March 1985.